Relation between electrode location and muscle fiber conduction velocity on m. biceps brachii using cross-correlation method

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Introduction

Muscle fiber action potential propagates from the motor end-plate to both ends of the muscle fiber (i.e., tendons) along the fiber without changing of its wave shape and its amplitude. This propagated velocity due to the action potential is called muscle fiber conduction velocity (i.e., MFCV), and can be estimated by using surface electrode. It was reported that MFCV ranged from 3 to 5 m/s for almost skeletal muscles. In the previous studies using multi-type surface electrodes, the values of MFCV were not constant and varied depending on the electrode location measured (Li and Sakamoto, 1996). Particularly, the comparatively large values of MFCV were obtained around both the motor end-plates zone and the tendon. The aim of this study was to elucidate relation between MFCV and electrode location measured. To obtain the propagating properties of motor unit action potentials (MUAPs), the wave shape and the amplitude for MUAPs were applied to obtain the MFCV.

Methods

The subjects were 10 healthy male volunteers aged 22 to 26 years. The experiment system was shown in Figure 1. Surface EMG was measured by using array electrodes at proximal side from the belly on m. biceps brachii at 20% of maximum voluntary contraction (MVC). The array electrodes were composed of 17 Ag wires with a diameter of 1 mm and a length of 10 mm. The inter-electrode distance was 5 mm. Detected surface EMG were derived with differential amplifiers for each adjacent paired wire. The differential amplifiers were set up a gain of 60 dB/decade and a bandwidth from 5 Hz to 1 kHz. The amplified EMG signals of 16 channels were digitized through an A/D converter with the sampling frequency of 50 kHz and with 14-bit resolution. After the measurement, the surface EMG of two seconds was used as the signal analysis since the contraction force was stable. To estimate the conduction delay from the adjacent electrodes of the motor unit action potential (MUAP), a single MUAP with a data point of 5,000 (i.e., duration of 100 ms) was extracted from surface EMG with use of extracting technique (Li and Sakamoto, 1996). Extracted one MUAP of 16 channels was superimposed 20 times in order to detect clearly waveform and to obtain high signal to noise ratio.

The values of MFCV between neighboring electrodes were calculated by two techniques of peak maximum method (Li and Sakamoto, 1996) and cross-correlation method (Sollie, et al., 1985). For the peak maximum method, the time delay was evaluated from the time difference (T_s) between main maximum peaks of signals. For the cross-correlation method, the cross-correlation coefficient $R_{xy}(T)$ between the signals $x(t)$ and $y(t)$ of neighboring channels was calculated by following equation,

$$R_{xy}(T) = \frac{\Phi_{xy}(T) - m_x \cdot m_y}{\sqrt{\Phi_x(0) - m_x^2} \cdot \sqrt{\Phi_y(T) - m_y^2}}$$

where $\Phi_{xy}(T)$ was cross-correlation function, $\Phi_x(0)$ and $\Phi_y(T)$ were auto-correlation functions of the signals $x(t)$ and $y(t)$ for time shift $T$, $m_x$ and $m_y$ were means of the signals $x(t)$ and $y(t)$, respectively. When the correlation coefficient $R_{xy}(T)$ reached maximum at shift time $T=T_s$, the shift time $T_s$ was equal to the time delay between two signals of $x(t)$ and $y(t)$. Thus, the time delay $T_s$ of respective channels was obtained by using two procedures. The MFCV could be calculated using the formula $MFCV = D_e / T_s$, where $D_e$ was the inter-electrode distance. The relative amplitude ratio between two signals was also evaluated at time delay $T_s$ as followed:

$$AMP_{ratio} = \begin{cases} \sqrt{\Phi_x(T_s) / \Phi_x(0)} & (\Phi_x(0) \geq \Phi_x(T_s)) \\ \sqrt{\Phi_y(0) / \Phi_y(T_s)} & (\Phi_y(0) < \Phi_y(T_s)) \end{cases}$$

The statistical difference in each parameter (n=10) was analyzed by t-test for paired data between the neighboring channels.
Results
For the peak maximum method, the mean and standard deviation (SD) was shown in Figure 2. The values of MFCV varied depending on the distance from the motor end-plates zone. At near the motor end-plates zone ($L_e=5$ mm) and the end of muscle ($L_e=45-50$ mm) that was called tendon zone, the values of MFCV significantly increased by a level of 1%. This result was good agreement with the previous results (Li and Sakamoto, 1996).

For the cross-correlation method, the values of mean and SD for three parameters (MFCV, maximum correlation coefficient and amplitude ratio) were shown in Figure 3. The mean values of three parameters varied depending on the distance from the motor end-plates zone. In the MFCV, the difference of values between the peak maximum method and the cross-correlation method was not recognized. In Figure 3(a), the mean values of MFCV indicated large value more than 7.0 m/s near the motor end-plates zone. And the values decreased in accordance with increase of the distance from the motor end-plates zone and MFCV at the locations between 10 mm and 40 mm showed around 3.88 m/s. Near the tendon zone, the values of MFCV rapidly increased more than 5.5-10.0 m/s again. As shown in Figure 3(b) and (c), the values of MFCV varied depending on the maximum correlation coefficient ($R_{xy(T_s)}$) and the amplitude ratio ($AMP_{ratio}$). The values of MFCV significantly increased near both locations of motor end-plates zone and the tendon zone, when the maximum correlation coefficient and the amplitude ratio significantly decreased and they indicated less than 0.90 and 0.80, respectively. When comparatively large and steady values of correlation coefficient ($R_{xy(T_s)}=0.975$) and amplitude ratio ($AMP_{ratio}=0.887$) were obtained at the locations 10 to 40 mm measured from the motor end-plates zone, the MFCV showed constant values of about 3.88 m/s. The values of the coefficient of variance (C.V.) were evaluated to elucidate a relation between the variances of three parameters and the electrode location as shown in Figure 4. The values of C.V. for each parameter in both locations of the motor end-plates and tendon zone were larger than those in other regions.

![Figure 1: A schematic diagram of experiment system and data processing for recording the surface EMG.](image)

![Figure 2: Distribution of MFCV with use of the peak maximum method. $L_e$ denotes the distance between motor end-plates zone and midpoint for bipolar electrodes.](image)
**Discussion**

The results of Figure 3 and 4 implied that the shape and the amplitude of MUAPs near the motor end-plates zone and the tendon zone were more changeable and more irregularly than those values in the other regions. There causes could be explained by both a difference of interference pattern of detected MUAPs around the motor end-plates zone (Basmajian and De Luca, 1985) and an influence of electrical property around the tendon zone (Roy et al., 1986). In conclusion, this result meant that a high maximum correlation coefficient and a high amplitude ratio were necessary for a reliable measurement of the MFCV.

**References**